Leading/nonleading charm production asymmetry in Σ^-p interactions.

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Abstract

The asymmetries between the spectra of leading and nonleading charmed mesons measured in Σ^-A interactions at p_L= 340 GeV/c in the WA89 experiment are described in the framework of Quark-Gluon String Model. There are two versions of the model under consideration: one of them includes the sea charm quark-antiquark pairs and the other one does not. It's shown that the asymmetries between D^- and D^+-meson spectra and between D_s^- and D_s^+- meson spectra can be fitted by QGSM curves obtained with the same parameters as charm asymmetry in π^-A experiments described in previous studies. The QGSM results are compared with the calculations in the next-to-leading approximation of perturbative QCD approach carried out by the other authors.

1 Introduction

The asymmetries between the spectra of D^- and D^+, D_s^- and D_s^+ mesons were measured recently in Σ^-A interactions at p_L= 340 GeV/c in the WA89 experiment [1]. It seems to be interesting to compare this asymmetries with those ones obtained in the π^-A experiments in order to understand the influence of quark composition of beam particle on a heavy flavored particle production and to extract some specific features of the strange-charmed meson spectra caused by the presence of a strange valence quark in Σ^- hyperon. The difference in x_F spectra($x_F = 2p_{II}/\sqrt{s}$) of leading and nonleading particles has been discussed recently and several theoretical models explained successfully the asymmetry as an effect of an interplay between the quark contents of the projectile and of the produced hadron. The charmed mesons containing ordinary quarks of the same type as beam particle have higher average x value. The asymmetry, defined as:

$$A(x) = \frac{dN^{D^-}/dx - dN^{D^+}/dx}{dN^{D^-}/dx + dN^{D^+}/dx}, \tag{1}$$

is a function rising with x. There are two different approaches in the theory for the description of this effect. The first one is based on perturbative theory of QCD. It takes into account the recombination of 'intrinsic charm'

quarks with valence quarks of the projectile as an origine of the asymmetry

[3]. The other phenomenological models exploit the properties of fragmentation functions in order to insert the asymmetry . We will not discuss here the details of recombination models but we are going to concentrate on a nonperturbative approach known as the Quark Gluon String Model (QGSM) [4]. This model fits well the leading/nonleading charm asymmetry for π^-p experiments [5].

2 The Quark Distributions in QGSM.

The inclusive production cross section of D-mesons is written as a sum over n-Pomeron cylinder diagrams:

$$f_1 = x\frac{d\sigma^D}{dx}(s,x) = \int E\frac{d^3\sigma^D}{d^3p}d^2p_\perp = \sum_{n=0}^{\infty}\sigma_n(s)\varphi_n^D(s,x) \tag{2}$$

where function $\varphi_n^D(s,x)$ is a particle distribution in the configuration of n cut cylinders and σ_n is the probability of this process. The parameter of the supercritical Pomeron used here is $\Delta_P = \alpha_P(0) - 1 = 0,12$. The detailed formulae for σ_n and φ_n^D in pp-interactions can be found in [6].

The distribution functions in case of Σ^--p collisions are:

$$\varphi_n^D(s,x) = a_0^D(F_q^{(n)}(x_+)F_{qq}^{(n)}(x_-) + F_{qq}^{(n)}(x_+)F_q^{(n)}(x_-) + 2(n-1)F_{q_{sea}}^{(n)})F_{\bar{q}_{sea}}^{(n)}(x_-), \tag{3}$$

where a_0^D is the density parameter of quark-antiquark chain fragmentation into the given type of mesons.

The particle distribution on each side of chain can be build on the account of quark contents of beam particle ($x_+ = (x + \sqrt{x^2+x_\perp^2})/2$, $x_\perp = 2m_\perp/sqrts$) and of target particle ($x_- = (x - \sqrt{x^2+x_\perp^2})/2$):

$$\begin{aligned}
F_q^{(n)}(x_+) &= \frac{1}{3}F_s^{(n)}(x_+) + \frac{2}{3}F_d^{(n)}(x_+),\\
F_{qq}^{(n)}(x_+) &= \frac{1}{3}F_{dd}^{(n)}(x^+) + \frac{2}{3}F_{ds}^{(n)}(x_+),\\
F_q^{(n)}(x_-) &= \frac{1}{3}F_d^{(n)}(x_-) + \frac{2}{3}F_u^{(n)}(x_-),\\
F_{qq}^{(n)}(x_-) &= \frac{1}{3}F_{uu}^{(n)}(x_-) + \frac{2}{3}F_{ud}^{(n)}(x_-).
\end{aligned} \tag{4}$$

Each $F_i(x_\pm)$ is constructed as the convolution:

$$F_i(x_\pm) = \int_{x_\pm}^{1} f_{\Sigma^-}^i(x_1)\frac{x_\pm}{x_1}\mathcal{D}_i^D(\frac{x_\pm}{x_1})dx_1, \tag{5}$$

where $f^i(x_1)$ is a structure function of i-th quark wich has a fraction of energy x_1 in the interacting hadron and $\mathcal{D}_i^D(z)$ is a fragmentation function of this quark into the considered type of D or D_s-mesons.

The structure functions of quarks in interacting proton have already been described in the previous papers [6]. In the case of hyperon they depend on the parameter of the Regge trajectory of φ-mesons ($s\bar{s}$) because of s-quark contained in Σ^-:

$$\begin{aligned}
f_{\Sigma^-}^d(x_1) &= C_d^{(n)}x_1^{-\alpha_R(0)}(1-x_1)^{\alpha_R(0)-2\alpha_N(0)+\alpha_R(0)+n-1},\\
f_{\Sigma^-}^{dd}(x_1) &= C_{dd}^{(n)}x_1^{\alpha_R(0)-2\alpha_N(0)}(1-x_1)^{-\alpha_\varphi(0)+n-1},\\
f_{\Sigma^-}^{ds}(x_1) &= C_{ds}^{(n)}x_1^{\alpha_R(0)-2\alpha_N(0)+\alpha_R(0)-\alpha_{\varphi(0)}}(1-x_1)^{-\alpha_R(0)+n-1},\\
f_{\Sigma^-}^{s}(x_1) &= C_s^{(n)}x_1^{-\alpha_\varphi(0)}(1-x_1)^{\alpha_R(0)-2\alpha_N(0)+\alpha_R(0)-\alpha_\varphi(0)+n-1},
\end{aligned}$$

(6)

(7)

where $\alpha_\varphi(0)$=0. The constants $C_i^{(n)}$ are determined by normalization conditions:

$$\int_0^1 f_i(x_1)dx_1 = 1.$$

3 The Fragmentation Functions.

The fragmentation functions are constructed for the quark and diquark chains according to the rules proposed in [7]. The following favoured fragmentation function into D_s^--mesons was written for the strange valence quark:

$$\mathcal{D}_s^{D_s^-}(z) = \frac{1}{z}(1-z)^{-\alpha_\psi(0)+\lambda}(1+a_1^{D_s}z^2), \tag{8}$$

where λ=$2\alpha'_{D^*}(0)\bar{p}^2_{\perp D^*}$. An additional factor $(1+a_1^{D_s}z^2)$ provides the parametrization of the probability of heavy quark production in the interval z=0 to z $\to$ 1. The values of the constant $a_1^{D_s}$ will be discussed later.

The function for the nonleading fragmentation of d-quark chain is:

$$\mathcal{D}_d^{D^+}(z) = \frac{1}{z}(1-z)^{-\alpha_R(0)+\lambda+2(1-\alpha_R(0))+\Delta_\psi}, \tag{9}$$

where $\Delta_\psi = \alpha_R(0) - \alpha_\psi(0)$. The function of the nonleading fragmentation of the diquark chain is the following:

$$\mathcal{D}_d^{D_s^-}(z) = \frac{1}{z}(1-z)^{-\alpha_\varphi(0)+\lambda+2(1-\alpha_R(0))+\Delta_\psi} \tag{10}$$

where $\alpha_R(0)$=0.5 and $\Delta_\psi = \alpha_R(0) - \alpha_\psi(0)$.

The following fragmentation function corresponds to the version of the diquark fragmentation into D_s^--mesons:

$$\mathcal{D}_{ds}^{D_s^-}(z) = \frac{1}{2z}(1-z)^{\alpha_R(0)-2\alpha_N(0)+\lambda+\Delta_\psi}(1+a_1^{D_s}z^2) + \frac{1}{2z}(1-z)^{\alpha_R(0)-2\alpha_N(0)+\lambda+\Delta_\varphi+\Delta_\psi+1} \tag{11}$$

4 The Asymmetry Suppression Causes.

Some fractions of sea quark pairs in hyperon, $d\bar{d}$ and $s\bar{s}$, are to be taken into account as far as they suppress the leading/nonleading asymmetry. The structure functions of ordinary quark pairs in the quark sea of hyperon can be written by the same way as the valence quark distributions:

$$f_{\Sigma^-}^d(x_1) \quad = \quad C_{d,\bar{d}}^{(n)} x_1^{-\alpha_R(0)}(1-x_1)^{\alpha_R(0)-2\alpha_N(0)+\Delta_\varphi+n-1+2(1-\alpha_R(0))}, \tag{12}$$

where sea quarks and antiquarks have an additional power term $2(1-\alpha_R(0))$ corresponding to the quark distribution of two pomeron diagram which includes one sea quark pair.

The structure function for strange sea quarks obeys the same rules:

$$f^{d}_{\Sigma^-}(x_1) \quad = \quad C^{(n)}_{s,\bar{s}} \delta_{s,\bar{s}} x_1^{-\alpha_\varphi(0)} (1-x_1)^{\alpha_R(0)-2\alpha_N(0)+\delta_\varphi+n-1+2(1-\alpha_R(0))} \tag{13}$$

where $\Delta_\varphi = \alpha_R(0) - \alpha_\varphi(0)$ and $\delta_{s,\bar{s}}$=0.25 (see [8]).

The fragmentation function of strange sea quark(or antiquark) into D_s mesons has the following form for mesons of the both charges:

$$\mathcal{D}^{D_s^-}_{s,\bar{s}}(z) = \frac{1}{z} z^{1-\alpha_\varphi(0)} (1-z)^{-\alpha_\varphi(0)+\lambda+2(1-\alpha_R(0))+\Delta_\psi} \tag{14}$$

The additional fragmentation parameter $a_f^{D_s}$ is equal to the fragmentation parameter for D-mesons.

5 The Intrinsic Charm Distribution.

As soon as we accounted $d\bar{d}$ and $s\bar{s}$ fraction in the quark sea of hyperon some fraction of charmed sea quark are to be considered as well. This small heavy quark admixture plays an important role due to its strong impact on the difference between leading and nonleading charmed meson spectra.

The charmed sea quark structure function is similar to the distribution of strange sea quarks:

$$f^{c,\bar{c}}_{\Sigma^-}(x_1) \quad = \quad C^{(n)}_{c,\bar{c}} \delta_{c,\bar{c}} x_1^{-\alpha_\psi(0)} (1-x_1)^{\alpha_R(0)-2\alpha_N(0)+\Delta_\varphi+n-1+2(1-\alpha_R(0))} \tag{15}$$

where $\delta_{c,\bar{c}}$ is the weight of charm admixture in the quark sea of hyperon. In fact it is not neseccarily to be equal to the charmed quark fraction in quark sea of pion [5]. This is only one parameter we can vary for Σ^- interaction after the best fit of pion experimental data which had been done before. The value of $\delta_{c,\bar{c}}$ can be estimated in the description of the WA89 data on D_s and D meson asymmetries.

Fragmentation functions are the following:

$$\mathcal{D}^{D^-}_{c,\bar{c}}(z) = \frac{1}{z} z^{1-\alpha_\psi(0)} (1-z)^{-\alpha_R(0)+\lambda} \tag{16}$$

and for D_s :

$$\mathcal{D}^{D_s^-}_{c,\bar{c}}(z) = \frac{1}{z} z^{1-\alpha_\psi(0)} (1-z)^{-\alpha_\varphi(0)+\lambda} \tag{17}$$

6 The Final Plots and The Comparisons.

The main parameter of QGSM scheme which is responsable for leading/nonleading charm asymmetry is a_1. It is the parametrization parameter of leading fragmentation function dependence on z $\to$ 1. The fraction of charmed sea quarks, $\delta_{(c,\bar{c})}$, is the second parameter in this calculations which makes the asymmetry lower because of the equal amounts of D^+ and D^- mesons produced by each sea charmed quark pair. Two sets of this couple of parameters were chosen in the description of $\pi^- A$ reaction data: a_1=4, $\delta_{(c,\bar{c})}$=0 and a_1=

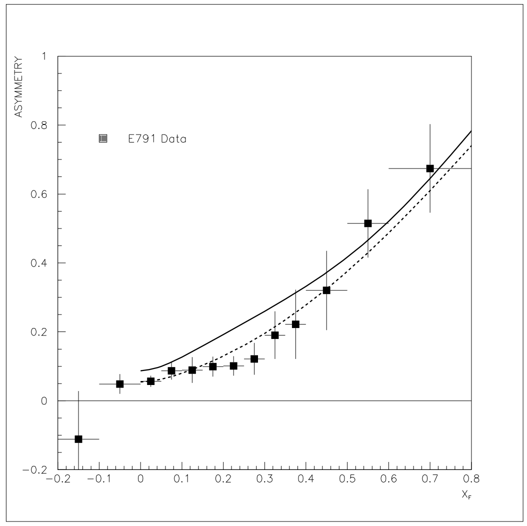

Figure 1: Asymmetry between D^- and D^+ spectra obtained in E791 (black squares) [2] and QGSM curves at two versions of parameters: solid line corresponds to the following set of parameters $a_1 = 10, \delta_{(c,\bar{c})} = 0.05\sqrt{a_0^D}$; dashed line is a result of QGSM fit with $a_1 = 4, \delta_{(c,\bar{c})} = 0$.

10, $\delta_{(c,\bar{c})} = 0.05\sqrt{a_0^D}$. We concider here these two values of a_1 taking the $\delta_{(c,\bar{c})}$ as more or less free parameter.

The two curves displayed in Fig.1 represent the fits of E791 pion beam experiment data [2] with two sets of parameters discussed above. Data of the WA89 experiment are given in Fig.2 and Fig.3 with the same parameters. It should be mentioned that the smaller fraction of charmed sea quarks was taken into account ($\delta_{(c,\bar{c})} = 0.01\sqrt{a_0^D}$ for to describe both $D^-/D^+ and D_s^-/D_s^+$ asymmetries with the fragmentation parameter $a_1 = 10$.

The resulting curves obtained in several theoretical models [11, 12] are also shown in these Figures as well.

7 Conclusions.

There are several conclusions derived from the calculations discussed in the article:

1) Data of the WA89 experiment on charm production asymmetry can be described within the framework of Quark-Gluon String Model with the same asymmetry parameter $a_1 = 10.$ as E791 data for $\pi^- A$ reaction.

2) D^-/D^+ and D_s^-/D_s^+ asymmetries measured with Σ^- beam are more sensitive to the weight of charmed quark pairs in the quark sea of interacting hyperon ($\delta_{(c,\bar{c})}$=0.01) than it could be seen at π^- beam interaction ($\delta_{(c,\bar{c})}$=0.05).

3) D_s^-/D_s^+ asymmetry is higher than D^-/D^+ asymmetry because strange quark pairs suppressing the asymmetry at D_s production have lower weight in quark sea of hyperon than ordinary $d\bar{d}$ pairs which cause the suppression of D^-/D^+ meson asymmetry.

4) The both of charmed meson asymmetries are nonzero values at x_F=0 in these

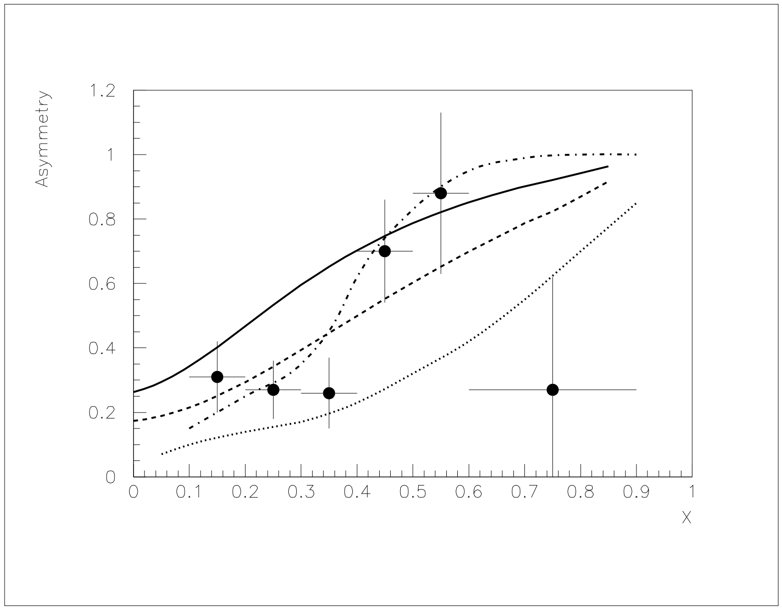

Figure 2: D^-/D^+ asymmetry measured in WA89 and theoretical calculations: solid line corresponds to the following set of QGSM parameters $a_1 = 10, \delta_(c,\bar{c}) = 0.01\sqrt{a_0^D}$; dashed line is a result of QGSM fit with $a_1 = 4, \delta_{(c,\bar{c})} = 0$; dashed-dotted line is the result of [11] and dotted line corresponds to A(x) predicted in [12].

calculations at WA89 energy and diminish with the increasing of energy.

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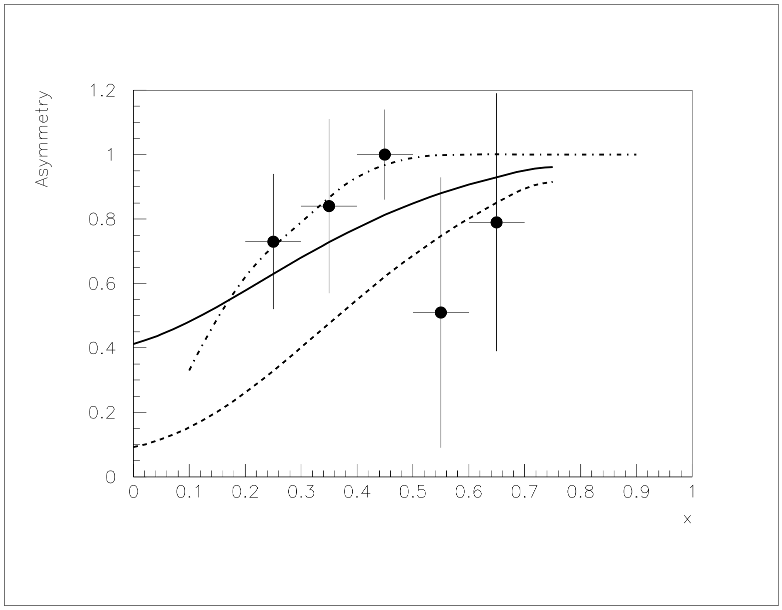

Figure 3: D_s^-/D_s^+ asymmetry measured in WA89 [1]; theoretical curves are the same as in Fig.2.

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